

UNITED STATES PATENT APPLICATION

**ENGINE-GENERATOR SET SYSTEMS AND METHODS
PROVIDING LOAD POWER FAULT PROTECTION**

INVENTOR

Mark H. Schultz
of Shoreview, Minnesota, U.S.A.

Jon Pehling
of Stacy, Minnesota, U.S.A.

10066613.005002

Attorney: Suneel Arora

Reg. No. 42,267

Schwegman, Lundberg, Woessner, & Kluth, P.A.

1600 TCF Tower

121 South Eighth Street

Minneapolis, Minnesota 55402

ATTORNEY DOCKET NO. 01094.183US1

ENGINE GENERATOR SET SYSTEMS AND METHODS PROVIDING LOAD POWER FAULT PROTECTION

TECHNICAL FIELD

5 This document relates generally to providing electrical power from a fuel-powered generator and particularly, but not by way of limitation, to engine-generator set systems and methods providing load power fault protection.

BACKGROUND

10 Both businesses and households rely on electrical equipment powered from one-phase, two-phase, three-phase, or other suitable utility-provided alternating-current (AC) power sources. However, commercial power reliability may not suffice for certain applications, for example, for computer facilities, hospitals, banking systems, or industrial motor loads. Therefore, a backup—or even an
15 independent—local power source may be desirable to provide a supplement to or substitute for a utility-provided AC power source.

 One type of a local power source is a static system, which typically uses an inverter to generate the load's AC power from a direct current (DC) battery bank. Providing power from such a static system for an extended period of time, however,
20 may require a large and costly bank of batteries. Another type of local power source is a rotary system, which typically uses a fuel-powered engine to rotate the shaft of an AC generator to produce an AC load current for an extended period of time. The engine, generator, and associated control mechanisms are sometimes referred to collectively as a "generator set" or "genset." Both the generator and the engine of a
25 genset may be damaged by an excessive electrical load. Moreover, certain protection schemes may protect the AC generator, but not the engine, from damage. Gensets using engines powered by natural gas or liquid propane ("LP") gas are particularly susceptible to possible damage resulting from supplying an excessive electrical load. For these and other reasons, the present inventors have recognized a
30 need for improved techniques of protecting genset components.

SUMMARY

This document describes, among other things, systems and methods providing load fault power protection to an engine-generator set. In one example, the engine-generator set includes a load power fault protector circuit that detects
5 when the power delivered to the load reaches a predetermined maximum power value, and substantially prevents the load power from exceeding the predetermined maximum value by decreasing the load voltage.

Among other things, this document describes an example of an overload protection apparatus for protecting an engine-generator set from damage. The
10 overload protection apparatus includes a load power sensing circuit and a voltage regulator circuit. The load power sensing circuit includes an input configured for coupling to an engine-generator set load, and an output providing a load power signal measuring an indication of power delivered from the engine-generator set to the load. The voltage regulator circuit includes an output configured for coupling to
15 a control input of a generator exciter circuit to control a voltage delivered from a generator to the load. The voltage regulator circuit also includes an input coupled to the load power sensing circuit output to receive the measured load power indication. In this example, the voltage regulator is configured to decrease a magnitude of the voltage delivered from the engine-generator set to the load when the measured load
20 power indication reaches a predetermined maximum value to substantially prevent the load power delivered from the engine-generator set to the load from exceeding a maximum load power value.

Among other things, this document also describes an example of an engine generator set including an engine, a generator, a load power sensing circuit, and a
25 voltage regulator circuit. In this example, the generator is mechanically coupled to and driven by the engine, and includes an output configured to be coupled to a load for providing electrical power signal to the load. The generator includes a generator exciter circuit controlling a load voltage of the electrical power signal provided to the load using a signal received at a generator exciter circuit control input. The load

power sensing circuit includes an input configured for coupling to the load and an output providing a load power signal measuring an indication of power delivered from the generator to the load. The voltage regulator circuit includes an output configured for coupling to the generator exciter circuit control input to control the load voltage. The voltage regulator circuit also includes an input coupled to the load power sensing circuit output to receive the measured load power indication. In this example, the voltage regulator circuit is configured to decrease a magnitude of the load voltage when the measured load power indication reaches a predetermined maximum value to substantially prevent the load power delivered from the engine-generator set to the load from exceeding a maximum load power value.

Among other things, this document also describes a method of generating AC electrical power and delivering the electrical power to a load. In one example, this includes sensing a load power delivered by an engine-generator set to a load, determining whether the delivered load power has reached a maximum load power value, and, if the delivered load power has reached a maximum load power value, then decreasing a load voltage to clamp the load power about the maximum load power value. Other examples will be apparent on reading the following detailed description and viewing the drawings that form a part thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are offered by way of example, and not by way of limitation, and which are not necessarily drawn to scale, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

Figure 1 is a schematic/block diagram illustrating generally, by way of example, but not by way of limitation, one example of portions of an engine-generator set (“genset”) including a load power fault protector circuit.

Figure 2 is a schematic/block diagram illustrating generally, by way of

example, but not by way of limitation, one conceptualization of portions of engine-generator set that illustrates how, during overload load power conditions, the load power control feedback loop interacts with the load voltage control feedback loop to decrease the load voltage to substantially prevent the load power from exceeding a predetermined maximum load power value.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings which form a part hereof. These drawings show, by way of illustration, specific embodiments of practicing the invention. This document describes these embodiments in sufficient detail to enable those skilled in the art to practice the invention. One should understand that the embodiments may be combined, other embodiments may be utilized, or structural, logical and/or electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

Figure 1 is a schematic/block diagram illustrating generally, by way of example, but not by way of limitation, one example of portions of an engine-generator set ("genset") 100 including a load power fault protector circuit 105. Genset 100 is coupled, at node/bus 110, to an electrical load 115 to which genset 100 provides electrical power. In this example, genset 100 includes an engine 120, which is mechanically coupled to drive an AC electrical generator 125. In one example, engine 120 is powered by a gaseous fuel source, such as propane or natural gas; such an engine 120 may be particularly vulnerable to damage caused when load 115 draws excessive electrical power. In other examples, engine 120 includes a gasoline engine, a diesel engine, a reciprocating internal combustion engine, a gas turbine, a steam turbine, a Sterling engine, a rotary engine, or any other engine capable of providing mechanical energy for driving generator 125. In this example, generator 125 provides a two-phase, three-phase, or other multiphase AC electrical

power signal, at node/bus 110, to load 115.

In the example of Figure 1, the frequency of the delivered AC electrical power depends on the speed of engine 120. In order to provide electrical power to load 115 at the desired frequency, the speed of engine 120 is controlled, such as by a frequency control feedback loop. In one such example, a frequency-sensing circuit 130 includes an input coupled to genset output node/bus 110 to sense the load signal frequency (or, in an alternate example, is coupled directly to engine 120 to sense its rotational frequency). Frequency sensing circuit 130 includes an output providing, at node/bus 135, a load frequency signal, indicative of load signal frequency, to frequency regulator circuit 140. Frequency regulator circuit 140 compares the load frequency signal at node/bus 135 to a reference frequency, and provides an output signal, at node/bus 145, to an input of throttle control circuit 150 to adjust the fuel provided at 155 to engine 120 to increase or decrease engine speed. Examples of suitable frequency control systems and methods are described in Schultz et al. U.S. Patent No. 5,006,781 entitled "MICROPROCESSOR BASED INTEGRATED GENERATOR SET CONTROLLER APPARATUS AND METHOD," assigned to Onan Corp., which is incorporated herein by reference in its entirety, including its disclosures of genset frequency control.

In the example of Figure 1, the magnitude of the line voltage delivered at genset output node/bus 110 to load 115 is also controlled, such as by a voltage control feedback loop. In one such example, a load voltage sensing circuit 160 includes an input coupled to genset output node/bus 110 to sense the magnitude of the load voltage signal. Load voltage sensing circuit 160 includes an output, at node/bus 165, that provides a load voltage signal, indicative of the load voltage signal magnitude, to an input of voltage regulator circuit 170. Voltage regulator circuit 170 compares the load voltage signal at node/bus 165 to a reference voltage, and provides an output signal, at node/bus 175, to an input of generator exciter circuit 180. In response, generator exciter circuit 180 adjusts, at node/bus 185, a winding excitation signal provided to generator 125, which, in response, adjusts the

load voltage signal magnitude at output node/bus 110. Examples of suitable output voltage magnitude control systems and methods are described in Schultz et al. U.S. Patent No. 5,006,781 entitled "MICROPROCESSOR BASED INTEGRATED GENERATOR SET CONTROLLER APPARATUS AND METHOD," assigned to Onan Corp., which is incorporated herein by reference in its entirety, including its disclosure of genset output voltage magnitude control.

The example of Figure 1 also includes a load current sensing circuit 190, a portion of which is interposed between generator 125 and load 115 for sensing the amount of current delivered from generator 125 to load 115. Load current sensing circuit 190 includes an input, coupled at node/bus 195, for receiving a portion of the current being delivered to load 115 (or a scaled replicate thereof). In one example, load current sensing circuit 190 includes an output that provides to generator 125, at node/bus 196, a sensed load current signal, indicative of the load current delivered to load 115. In one example, generator 125 uses the sensed load current signal for controlling a circuit breaker, or other current control mechanism of generator 125, in the event of a short circuit or current overload. Examples of suitable output current circuit interrupter systems and methods are described in Schultz et al. U.S. Patent No. 5,006,781 entitled "MICROPROCESSOR BASED INTEGRATED GENERATOR SET CONTROLLER APPARATUS AND METHOD," and Schultz U.S. Patent No. 5,701,070 entitled "ELECTRICAL GENERATOR DAMAGE PROTECTION APPARATUS AND METHOD WITH CIRCUIT BREAKER TRIP INITIATION," each of which is assigned to Onan Corp., and each of which is incorporated herein by reference in its entirety, including their disclosure of genset output current interruption and control.

The example of Figure 1 also includes a load power fault protector circuit 105. In one example, load power fault protector circuit 105 protects generator 125 and engine 120 when load 115 attempts to draw excessive power from genset 110, such as by activating a load power control feedback loop when the load power reaches a predetermined maximum load power value. In the example of Figure 1,

load power fault protector circuit includes a load power calculation circuit 197 including an input, coupled at node/bus 165, to the load voltage sensing circuit 160 to receive the load voltage signal. Another input of load power calculation circuit 197 is coupled, at node/bus 196, to load current sensing circuit 196 to receive the load current signal. By multiplying the received load voltage and load current signals (including multiplication by a power factor calculated from a cosine of the phase angle between the load voltage and load current signals) load power calculation circuit calculates the real power being delivered to load 115. Load power calculation circuit 197 includes an output that provides to a control input of voltage regulator circuit 170, at node/bus 198, a load power signal indicative of the power being delivered to load 115. In one example, when the load power signal at node/bus 198 indicates that the power delivered to load 115 has reached the predetermined maximum load power value, the voltage regulator circuit 170 operates to control generator exciter circuit 180 and generator 185 so as to reduce the magnitude of the load voltage at the genset output node/bus 110. This substantially prevents the load power provided by genset 110 from exceeding the predetermined maximum load power value, and protects generator 125 and engine 120 from damage resulting from providing excessive load power. Because such clamping of load power about the predetermined maximum load power value uses a feedback control loop, the transient load power may exceed the predetermined maximum load power value for a short period of time, depending on, among other things, the loop gain, stability, load characteristics, etc., however, the feedback control loop operates to reduce such an excess transient load power toward zero in the steady-state.

Figure 2 is a schematic/block diagram illustrating generally, by way of example, but not by way of limitation, one conceptualization of portions of engine-generator set 100 that illustrates how, during overload load power conditions, the load power control feedback loop interacts with the load voltage control feedback loop to decrease the load voltage to substantially prevent the load power from

exceeding a predetermined maximum load power value. The load power control feedback loop includes switch **200**, which is open when the load power is less than a predetermined maximum load power value. Under such conditions, the load voltage at node/bus **110** is determined by the load voltage control feedback loop.

5 The load voltage control feedback loop includes load voltage sensing circuit **160**, which includes an input coupled to the load **115** at genset output node/bus **110**. Load voltage sensing circuit **160** provides at node/bus **165** a load voltage signal indicative of the load voltage at node **110** to a negative input of an amplifier circuit or other summing (or difference) circuit **205**. A positive input of summing circuit
10 **205** receives, at node/bus **210**, from a reference voltage circuit a substantially stable or constant reference voltage to which the load voltage signal at node/bus **165** is compared. Summing circuit **205** includes an output that provides, at node/bus **215**, an “error” signal based on the difference between the load voltage signal at node/bus **165** and the reference voltage signal at node/bus **210**. In this example, the error
15 signal at node/bus **215** is received at an input of a proportional, integral, derivative (“PID”) or other load voltage regulator circuit **220**. One example of a PID regulator is described in the above-incorporated Schultz et al. U.S. Patent No. 5,006,781. Load voltage regulator **220** includes an output that provides, at node/bus **175**, a control voltage to generator exciter circuit **180**, for adjusting the winding excitation
20 of generator **125**, and in turn, regulating the load voltage at node/bus **110** to the desired value.

 In the example of Figure 2, the load power control feedback loop includes load power sensing circuit **225**, which includes an input coupled to the load **115** at genset output node/bus **110**. Load power sensing circuit **225** (which, in one
25 example, includes load voltage sensing circuit **160**, load current sensing circuit **190**, and load power calculation circuit **197**) provides, at node/bus **198**, a load power signal indicative of the power delivered from genset **100** to load **115**. The load power signal at node/bus **198** is received at a negative input of an amplifier circuit or other summing (or difference) circuit **230**. A positive input of summing circuit **230**

receives, at node/bus **235**, from a power reference circuit a substantially stable or constant reference power value that establishes a maximum load power value. Summing circuit **230** includes an output that provides, at node/bus **240**, an “error” signal based on the difference between the load power signal at node/bus **198** and the reference power value at node/bus **235**. The error signal at node/bus **240** is received at an input of a PID or other load power regulator circuit **245**. Load power regulator **245** includes an output that provides, at node/bus **250**, a control voltage that, in one example, is delivered when switch **250** is closed to a positive input, at node/bus **255**, of summing circuit **205**. This adjusts (e.g., decreases) the load voltage to substantially prevent the load power from exceeding the maximum load power value. Switch **250** is closed when the load power reaches the maximum load power value. Switch **250** is open when the load power is less than the maximum load power value to inhibit the load power control feedback loop during such conditions. In one example, switch **250** is controlled by coupling the error signal at node **240** to a control input of the switch, at node/bus **260**, through an amplifier, sign-circuit, comparator, or other resolving circuit **265** that resolves the error signal into appropriate signal levels for controlling switch **250**. The switch control configuration of Figure **2** is merely one example implementation. In an alternative example, the signal controlling switch **200** is generated using the load power signal at node **198**, which is compared to a separate reference power that may differ in value from the reference power at node **235**. In one embodiment, this comparison is made using a hysteresis comparator so that switch **200** closes when the load power at node/bus **255** exceeds an incremental value above the maximum load power value (e.g., an upper hysteresis point of 110% of maximum load power) and opens when the load power at node/bus **255** falls below an incremental value below the maximum load power value (e.g., a lower hysteresis point at 90% of maximum load power). In a further embodiment using such hysteresis, regulator **245** constrains the voltage at node **255** to be zero or negative, to ensure that the load voltage signal is not increased during the time when switch **200** remains closed as the load power is

falling below 100% but remains above the lower hysteresis point.

In one example, the load voltage and load power control feedback loops are implemented using analog circuit components. In another example, however, portions of one or both of these loops are implemented digitally or in software, such as by an appropriate sequence of instructions executed on a microprocessor, controller, state-machine, or similar configuration. Moreover, Figure 2 merely illustrates one example of interaction between load voltage and load power control feedback loops. For example, in an alternative embodiment, the error signal at node 255 is not provided to a positive input of summing circuit 205, but is instead used to control a gain or otherwise scale the reference voltage at node/bus 210 when the load power reaches the predetermined maximum power value.

In another example, the load power fault protector circuit 105 described herein with respect to Figures 1 and 2, is implemented in combination with other load control systems and techniques used by genset 110. In one example, genset 110 also includes current control circuits, such as described in the above-incorporated Schultz et al. U.S. Patent No. 5,006,781 and Schultz et al. U.S. Patent No. 5,701,070. In another example, genset 110 also includes a circuit for decreasing the load voltage as a function of a drop in frequency, as may occur temporarily when a substantial additional load is switched in. One suitable example of such a circuit and associated operative techniques is described in Schultz et al. U.S. Patent No. 5,006,781, entitled "MICROPROCESSOR BASED INTEGRATED GENERATOR SET CONTROLLER APPARATUS AND METHOD," assigned to Onan Corporation, which is incorporated herein by reference in its entirety, including its disclosure of devices and methods for decreasing load voltage as a function of generator frequency.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-discussed embodiments may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention

should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, the

5 terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

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